A SIMPLE SPECTROSCOPE AND ITS TEACHINGS.[1]

II.

Series.

MESSRS. RUNGE AND PASCHEN[2] first showed in 1890 that the spectra of lithium, sodium, and potassium were the summation of the spectra of various "series." Later they have shown that lead and other metals and the Cleveite gases follow suit.

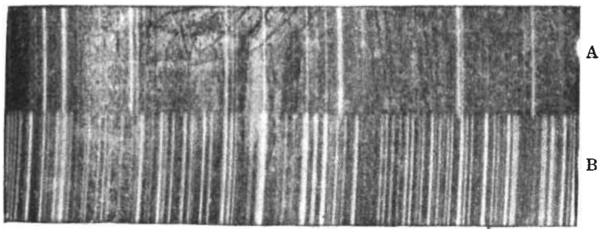

FIG. 7.—Parts of the spectra of (A) barium and (B) iron (from a photograph).

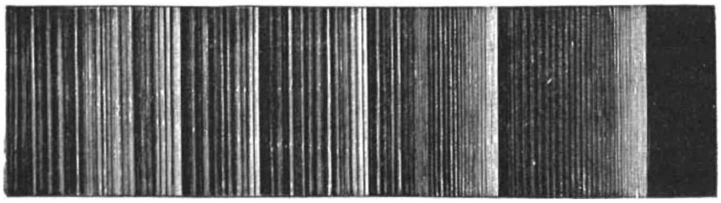

FIG. 8.—Fluting of carbon.

A "series" of spectral lines may be defined as a sequence of lines the intensity of which decreases with the wave-length, and the number of vibrations of which may be determined by the formula—

$$A + B/n^2 + C/n^4,$$

where n is given the integers from three upwards, and the constants A, B, and C are determined for each element separately.

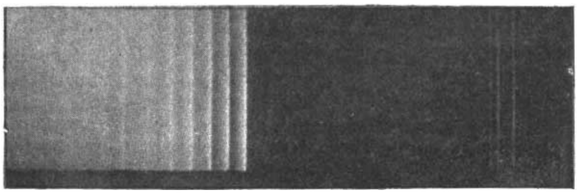

FIG. 9.—Fluting of magnesium.

The fact that lines must close up to one another, as the violet end of the spectrum is reached, indicates that the character of a "series" is best brought under notice in the ultra-violet end of the spectrum. In the visible part of the spectrum the lines forming "series" are too far apart to be recognised as belonging to series.

As soon as it becomes apparent that a set of lines in the violet seems to form a series, computation will at once give the lines that belong to it in the visible part of the spectrum.

The accompanying diagram (Fig. 10) shows how the apparently irregular lines observed in the spectra of the Cleveite gases can be arranged into the most exquisite order when the six series of lines which build up the spectra are shown separately.

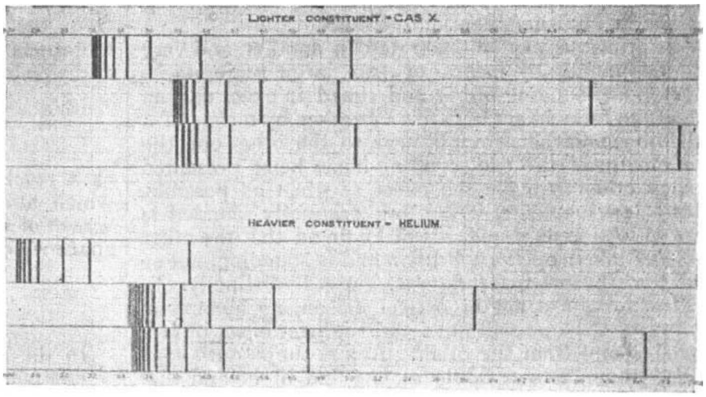

FIG. 10.—The series in the Cleveite gases.

Some of these series are composed of triplets instead of single lines.

I wrote thus on this subject in 1879:—

"I am at present engaged in investigating this question of rhythm, and I have already found that many of the first order lines of iron may probably arise from the superposition or integration of a number of rhythmical triplets. All this goes to show how long the series of simplifications is that we bring about in the case of the so-called elementary bodies by the application of a temperature that we cannot as yet define.

"Indeed, the more one studies spectra in detail, and especially under varying conditions of temperature which enable us to observe the reversal now of this set of lines, now of that, the more complex becomes the possible origin. Some spectra are full of doublets; others, again, are full of triplets, the wider member being sometimes on the more, sometimes on the less, refrangible side."[1]

Mascart[2] had noted this recurrence of similar features in spectra ten years earlier.

Discontinuous Spectra with Dark Lines.

It is time now to make still another experiment with our needle and prism.

If we study sunlight—taking care again to shield the prism, by allowing a sunbeam to illuminate the needle, we get a spectrum of a kind differing from those we have seen before, inasmuch as the continuous band of colour is broken, it is full of dark lines; that is, some of the coloured rays are lacking; and hence images of the needle are not forthcoming in places. The positions of some of the chief dark lines lettered by Fraunhofer are shown in Fig. 11.

We now know that this result is produced by what is termed the *absorption of light.* To understand it we have only to look at a candle through glasses of different colours: a blue glass absorbs or stops the blue light, and only the red end of the spectrum remains; a red glass absorbs or stops the red, and only the blue end remains.

In these cases large regions of the spectrum are alternately blotted out as differently coloured glasses are used, but the absorption with which we have to do mostly is of a more restricted character; lines, that is single images of the slit, are in question.

One of the most important things that has been gathered from the study of these absorption effects is that if we look at a light source competent to give us a continuous spectrum, through any of the vapours or gases we have so far considered as producing bright lines; provided the light source is hotter than the gases or vapours, the particular rays constituting the bright line or discontinuous spectrum of each of the vapours as gases will be cut out from the light of the continuous spectrum.

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[1] Continued from p. 373.

[2] *Abh. k. Akad. Wiss.*, Berlin, 1890.

[1] *Proc.* Roy. Soc., vol. xxviii., March 1879.

[2] In 1869, he wrote as follows: "Il semble difficile que la reproduction d'un pareil phénomène soit un effet du hasard: n'est-il pas plus naturel d'admettre que ces groupes de raies semblables sont des harmoniques qui tiennent à la constitution moléculaire du gaz lumineux? Il faudra sans

Explanation of Absorption.

While in the giving out of light we are dealing with molecular vibration taking place so energetically as to give rise to luminous radiation; absorption phenomena afford us evidence of this motion of the molecules when their vibrations are far less violent. The molecules can only vibrate each in its own period, and they will even take up vibrations from light which is passing among them, provided always that the light thus passing among them contains the proper vibrations.

An illustration from what happens in the case of sound will help to make this clear. If we go into a quiet room where there is a piano, and sing a note and stop suddenly, we find that note echoed back from the piano. If we sing another note, we find that it also is re-echoed from the piano. How is this? When we have sung a particular note, we have thrown the air into a particular state of vibration. One wire in the piano was competent to vibrate in harmony with it. It did so, and, vibrating after we had finished, kept on the note.

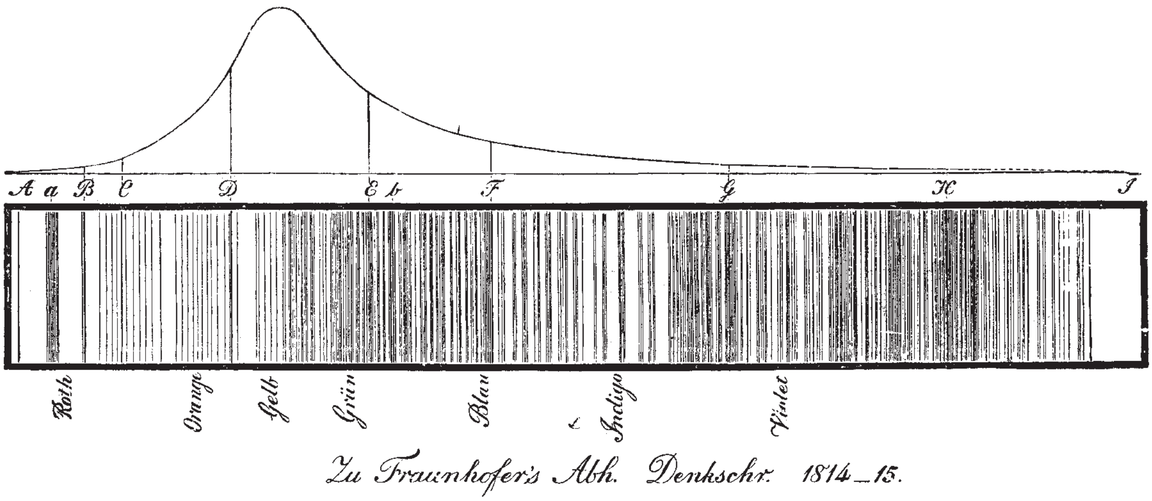

FIG. 11.—Copy of Fraunhofer's map of the solar spectrum.

This principle may be illustrated in another and very striking manner by means of two large tuning-forks mounted on sounding-boxes and tuned in exact unison. One of the forks is set in active vibration by means of a fiddle-bow, and then brought near to the other one, the open mouths of the two sounding-boxes being presented to each other to make the effect as great as possible. After a few moments, if the fork originally sounded is damped to stop its sound, it will be found that the other fork has taken up the vibration and is sounding, not so loudly as the original fork was, but still distinctly. If the two forks are not in perfect unison, no amount of bowing of the one will have the slightest effect in producing sound from the other. Again, suppose we have a long room, and a fiddle at one end of it, and that between it and an observer at the other end of the room there is a screen of fiddles, all tuned like the solitary one, we can imagine that in that case the observer would scarcely hear the note produced upon any one of the open strings of the solitary fiddle. Why? The reason is that the air-pulses set up by the open strings of this fiddle, in unison with all the others, would set all the other open strings in vibration; the air pulses set in motion by the vibration of the fiddle cannot set all those strings vibrating and still pass on to one's ear at the other end of the room as if nothing had happened to them.

Now apply this to light. Suppose we have at one end of a room a vivid light-source giving us all possible waves of light from red to violet. This we may represent as before by

V I B G Y O R

Also suppose that we have in the middle of the room a screen of molecules, say a sodium flame, capable of emitting yellow light,

Y

What will happen? Will the light come to our eyes exactly as if the molecules were not there? No; it will not. What, then, will be the difference? The molecules which vibrate at such a rate that they give out orange light, keep for their own purpose—filch, so to speak, from the light passing through them—the particular vibrations which they want to carry on their own motions, and we shall have

V I B G   O R

as a result; the light comes to us minus the vibrations which have thus been utilised, as we may put it, by the screen of vapour. We have, in fact, an apparently dark space which may be represented thus;

V I B G **Y** O R

In the spectroscope we see what would otherwise be a continuous spectrum, with a dark band across the yellow absolutely identical in position with the bright band observed when the molecules of the vapour of which the screen is composed radiated light in the first instance. It is not, however, a case of absolute blackness, or absence of that particular ray, for the molecules are set in vibration by the rays which they absorb, and

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doute un grand nombre d'observations analogues pour découvrir la loi qui régit ces harmoniques."

therefore give out some light, but it is so feeble as to appear black by contrast with the very much brighter rays coming direct from the original source.

This great law may be summed up as follows: *Gases and vapours, when relatively cool, absorb those rays which they themselves emit when incandescent;* the absorption is continuous or discontinuous (or selective) as the radiation is continuous or discontinuous (or selective).

I have referred to this matter at some length because in our light sources, in the sun, and in many of the stars we have light from a more highly heated centre passing through an envelope of cooler vapours, and on this account absorption phenomena are produced.

Our knowledge of the chemistry of the sun and stars is founded upon the exact coincidence of the bright lines seen in our laboratories with the dark lines noted in the spectra of those celestial bodies. The diagram shows the coincidence in the case of the double orange line of sodium vapour with dark lines in the spectrum of the sun.

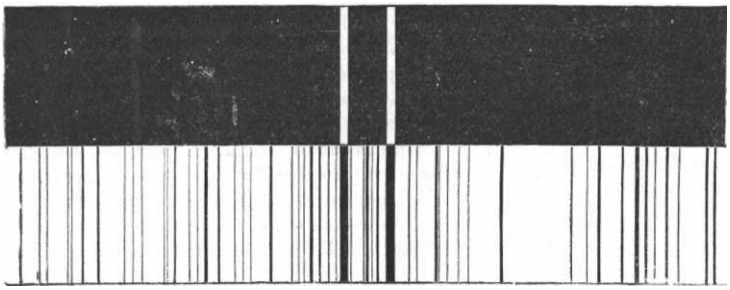

FIG. 12.—The coincidence of the bright double orange lines of sodium vapour with the dark lines, D, of Fraunhofer.

Now if my reader has not hesitated to invest his or her sixpence in a prism, and has had the patience (no other quality is needed) to do what I have suggested, the way is open to read with intelligence most books involving spectrum analysis which he or she is likely to come across; terms such as

Spectrum
Continuous spectrum
Grating
Prism
Spectroscope
Slit
Line spectra
Fluted spectra
Discontinuous (or selective) spectrum
Fraunhofer lines
Wave-length
Radiation
Absorption
Series

should now have acquired a definite meaning, and I trust the expressiveness of the terms will be acknowledged while they are accepted as part of the future mental stock-in-trade.

NORMAN LOCKYER.

TO CALCULATE A TABLE OF LOGARITHMS.

HAVING been asked to give a short course of lectures to working men, which involved an account of logarithms and the slide-rule, I felt that, although not important, there would be some advantage in being able to show them how they could calculate a table of logarithms and a table of antilogarithms for themselves. Not that they need do so except as an interesting exercise, for I do not think it necessary that a man or boy must be able to make a tool before he is allowed to use it, but it would do them no harm to explain to them a simple method if I could invent one.

Of course on the usual assumption that one must first understand the exponential theorem, it is absurd to think that even average schoolboys who have been six years at mathematics can understand how logarithms are calculated. But if a schoolboy has been told what a logarithm means, and if he can extract a square root by the ordinary arithmetical method, and especially if he has had a sensible teacher and been allowed to use tables of logarithms, I think that he will have no difficulty in understanding the following method, and will rather enjoy working at it a little.

Let him find $10^{1/2}$, $10^{1/4}$, $10^{1/8}$, $10^{1/16}$, $10^{1/32}$, by repeatedly extracting square roots, getting out his answers to five significant figures, say. Let him now by multiplication calculate $10^{3/32}$, $10^{5/32}$, &c., right up to 10^1. He thus has a table of which I give the beginning and end.

Number.	Logarithm.
1·0000	0·00000
1·0746	0·03125
1·1548	0·06250
1·2409	0·09375
1·3336	0·12500
.	.
.	.
.	.
8·0584	0·90625
8·6596	0·09750
9·3057	0·96875
10·0000	1·00000

If he plots these values on squared paper he gets a curve which enables him to find the logarithm of any number.

If he wants answers right to four significant figures, it is well to draw only a small part of the curve on one sheet of squared paper. Thus plotting the first three points so that the curve joining them (using a slightly bent straight-edge) passes diagonally through a small sheet of squared paper, one of my students has found answers which are sufficiently correct to impress a student with the value of the method. I give here seven values taken at random from the curves of the early and the late parts of the table. This was the first time that he had tried the method, and the small errors in the fourth significant figures are not likely to occur if a man has more practice.

Number.	Logarithm as measured.	Correct logarithm.
1·035	·0149	·0149
1·110	·0452	·0453
1·151	·0610	·0611
8·950	·9520	·9518
9·175	·9626	·9626
9·345	·9706	·9705
9·825	·9923	·9923

Even with the very cheapest squared paper we can construct tables of logarithms and antilogarithms which will be quite accurate to three significant figures, and by taking twice the trouble and using $10^{1/64}$ we may get a table accurate to four significant figures, even with very cheap paper. Also it is to be noticed that by using $10^{1/128}$ and higher roots, we can find the logarithm of any particular number with any amount of accuracy desired.

JOHN PERRY.

Royal College of Science, February 16.